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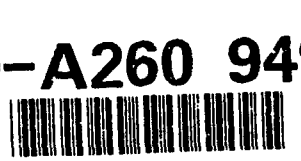

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DATA MODEL DEVELOPMENT AND VALIDATION FOR PRODUCT DATA EXCHANGE

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ABSTRACT

Data modeling techniques have been used extensively in the development of an emerging standard for the exchange of product design and manufacturing information. PDES, Inc., an industry cooperative, is applying resources to accelerate the development and implementation of this emerging standard, the Product Data Exchange Specification (PDES). An objective of PDES, Inc. is to validate the completeness and usability of the specification. This paper describes some strategic and technical issues which directly impact this effort. Experience with actual validation activities identified the need to develop additional requirements documentation. This paper serves as the background for a series of papers which will describe the actual methods and processes used in the requirements specification activity. Three types of results came out of this requirements activity. The form of the project deliverables changed considerably. Insights on conducting requirements activities were identified. New issues on the relationship of this work to portions of the specification were identified.

Introduction

The Product Data Exchange Specification (PDES) is an emerging standard for the exchange and integrated use of product information over the life-cycle of a product (fig. 1). This specification will play a key role in improving competitiveness and the ability to manufacture products in a world market [COO88].

The need for standardization has been nationally [HEN88] and internationally recognized. Subcommittee 4 of the International Standards Organization (ISO), Technical Committee 184 (TC184), passed a resolution describing the need for such a standard (Resolution 1, ISO TC184/SC4, July 1984); this need has been reaffirmed on a number of occasions. The development has required enormous amount of technical effort. There have been hundreds of contributors from a wide spectrum of industry. The national effort has been coordinated by the IGES/PDES

Organization [SMI89] and the international effort has occurred within Working Group 1 of ISO TC184/SC4. Both of these standards organizations have the common goal of having a single standard. The first working draft of the specification has been submitted to ISO TC184/SC4 [SMI88]. It has been registered with ISO as Draft Proposal 10303.

PDES differs from many existing standards in that it is not based upon any proven implementation. The scope, complexity, divergence of approaches, divergence of disciplines, and immediacy of need demand coordinated action. Achieving a quality standard which is useful across industry boundaries is of the utmost concern.

The ISO ballot on the draft proposal and the United States ballot response made two facts evident. First, an enormous amount of technical effort has been accomplished. Second, the effort is not complete and the content is untested. The ballot has identified what areas need the most effort as well as many specific deficiencies with some proposed solutions. In this respect, the ballot was positive. The ballot was the first comprehensive evaluation of the technical content, and it is helping to set the priorities of the committees involved in the development.

Another organization is also working towards the common goal of a quality standard. PDES, Inc. is a cooperative of more than twenty companies from the aerospace, automotive, computer, ship building, and other manufacturing sectors. PDES, Inc. was formed to accelerate the development, validation, standardization, and implementation of PDES. This organization has advantages over a standards organization of full-time resources, a restricted scope, and a more controllable organization. PDES, Inc. has government associates as well. The National Institute of Standards and Technology (NIST) is one; NIST's National PDES Testbed has participated by providing testing facilities, by contributing to test development, and through configuration control of the standards documents [FUR89]. The requirements effort described is being conducted by PDES, Inc. with NIST participation. All authors were part of this requirements activity.

The focus of this paper is on providing a framework for PDES, Inc. validation efforts and identify how this affects the PDES specification. Data modeling has been and continues to be a fundamental technology used in developing the specification. This report is designed to provide the foundation for a series of papers which will follow the process of using the formal description techniques for describing information requirements and for ensuring that a model which embodies these requirements is useful for the purpose intended. The series will describe:

1) the methodologies used for documenting requirements and developing information models;
2) the process of developing information models;
3) a methodology for model validation and a description of testing techniques; and
4) the development of test criteria, testing suites, test procedures and such.

The series will makes some important distinctions between appropriate validation techniques for models containing information requirements.

The rest of the discussion in this paper provides additional background material that will be needed to understand the series of papers. Certain barriers to providing effective feedback and acceptable technical solutions to the standards organizations have impacted the critical success factors for this project. Identifying criteria to judge the success of a project or requirements activity is very important.

After some experience was gained by PDES, Inc. project members, a review occurred in the form of a requirements activity. A brief introduction to this requirements activity is provided, and the results are described along with their effect on the PDES, Inc. project as a whole. The findings changed the form of the project deliverables considerably. Insights on conducting a requirements activities are identified. New issues on the relationship of this work to portions of the specification were identified. Finally, the current direction of the project is provided.

The Initial State

The PDES, Inc. project began its efforts with a collection of conceptual information models and the formal descriptive language models which were developed by the standards organization. The project was divided into three teams. One team focused on improvements to these baseline models such as completing the documentation. One team concentrated on testing and validating the models. The third team was responsible for the software environment and prototype implementations.

The decision was made in the first phase of the project to limit the scope to mechanical piece parts and rigid body assemblies. In addition, this initial phase was only concerned with PDES used for exchange purposes and not for the integrated sharing of product data between processes. The modeling team identified the subset of models needed for this purpose. This team studied, evaluated the quality of the modeling, and corrected deficiencies. The validation team developed a model validation methodology which was adapted from accepted software testing methodologies [HET88]. The implementation team concentrated on

putting together a prototyping environment. Some months of work took place, and reworked models were released as feedback to the standards organization. There were difficulties associated with completing the models and testing them. A limited number of these problems have more general relevance to data modeling projects, and these deserve discussion.

Barriers to Making it Work

The barriers to providing effective feedback and technical solutions that are accepted by the standards organization really fall into two categories: those which are related to PDES strategic issues and those which are technical issues. The strategic category includes scoping issues and the standard-making process. The technical concerns involve the use of multiple data modeling methodologies, the lack of proven techniques for validating conceptual models, and the lack of software tools that work together to aid in the development and testing.

The scope of PDES is enormous. PDES is envisioned to support all aspects of product description from initial conception through product design, manufacture, support and disposal. In addition to this, PDES is intended to support a broad industrial base. There is an analogy between this effort and any enterprise which attempts to get its information requirements under control. Any project which is accountable must restrict the scope of its efforts to something which is both useful and realistically accomplishable within the allowed schedule and resources. The challenge to the PDES, Inc. project has been to carve out a useful subset of the entire PDES effort, and at the same time to ensure that the piece will fit into the larger scheme. The challenge to the first data modeling project for an enterprise is to build a framework for information requirements and then to scope follow-on efforts into useful and manageable pieces.

The standards-making bodies must achieve a consensus on technical content before a standard can be achieved. Alternative technical solutions must be weighed, and one solution must be agreed upon. This consensus-building process can be difficult and lengthy. It is appropriate for each member of such an activity to have their own company's best interests in mind. A standards organization has no control over the available manpower or the skills that these resources have. Neither contract nor employment bind members to work commitments. The standards organization management must always rely upon the good will of corporate management to support their member contributions. A shortage of team skills, data modeling skills and technical publications skills have had a negative impact on the PDES development effort [DAY88].

The need to recognize that multiple agendas will exist, the need to obtain committed resources, and the need to have the correct balance of skills available are all project-planning issues. These issues were addressed by the PDES, Inc. requirements project, and they are relevant to other requirements projects and data modeling activities.

The technical issues are not any easier to solve. One technical issue has been the data modeling techniques. In developing PDES, a number of data modeling approaches have been used. EXPRESS is formal descriptive language for data definition. EXPRESS was chosen for writing the normative specification forwarded to ISO TC184 SC4. IDEF1X is a graphical semantic data modeling technique. An informational annex to the specification used IDEF1X. IDEF1X and other data modeling techniques were used to develop the information content embodied in the specification. Each committee within the IGES/PDES Organization chose the technique or techniques they found most appropriate [BUR89] although there were attempts to restrict their work to either IDEF1X, EXPRESS or both. Only IDEF and EXPRESS are being used in the PDES, Inc. efforts.

No proven translation utilities exist between IDEF1X and EXPRESS. There is no direct correspondence between all concepts, although a correspondence can be derived for a majority of concepts. While EXPRESS definitions can convey more concrete implementation decisions and more formalized constraints, the semantics of information should be compatible between the IDEF1X and the EXPRESS forms. The compatibility of semantic content is one key issue in validating the specification.

Another technical issue is related to the best approaches for testing conceptual information models. The initial months of experience with the software testing-based techniques led some project members to question whether there were better methods for verifying the quality and usefulness of these resources. The criteria found in the specification was either extremely high-level, such as design goals, or explicitly stated within the model to be tested. Many criteria that the testing team could derive readily were subjective, and there were questions of whether the criteria could address usefulness and usability issues. One sample question relates to the Geometry Model [sub-clause 4.3], is it meaningful to test the model's elements when they are only used when collected together with elements from other models? A test criteria task group was formed to analyze the techniques in use and to refine these techniques to make them more appropriate for testing information models.

The desired environment for developing complex formal specifications would include software tools that would both aid in the development and participate in the validation of the specification. Fragments exist which should be part of this

environment, but there is nothing which comes close to a comprehensive toolset for PDES. Such tools could play an important role in the fitness testing of information models. The testing tool set should include modules to check the syntax, to check the semantic consistency, to provide for constraint checking libraries, to support the convenient capture of test results, and to support a simulation environment. Many questions related to semantics, usefulness, and compatibility between IDEF1X models and EXPRESS specifications can only be answered by either simulation or actual implementation. Simulation techniques have promise and other standards efforts using formal descriptive techniques have found building a simulation environment to be essential [SIJ89].

Where the Effort Is

Management of the PDES, Inc. project chose to study the concerns raised during the initial months of experience by bringing together a small task-group. The most pressing concerns rested within the domain of testing and validation. The testing tasks were openly accepted as the most difficult to accomplish. The top priorities were to:

- Develop a testing approach that could evaluate "usefulness" by defining an applications framework for PDES.
- Develop criteria for the selection of targeted applications.
- Develop plans and justifications for follow-on activities.

The findings of this effort set the direction for the current efforts of the entire project.

Impact on the PDES, Inc. Project

The recommendations identified by the PDES, Inc. testing criteria task group have resulted in key refinements to the interactions between the teams. Modeling efforts are now focused on building context-driven integrated models (CDIMs) which focus on the information requirements of specific applications and identify how to apply the more general resources found in the topical models. Testing efforts are now focused on deriving acceptance criteria based upon what is useful to specific applications and are restricted to the use of PDES for exchange purposes. The implementation team now has much more specific requirements and priorities for the tools needed for model development and model testing.

Lessons for Requirements Activities

The task team developed a set of lessons learned from their experience for the follow-on activities. We believe that some of them have a more general application to activities beyond what we are currently tasked to accomplish. These are:

- Any project needs to gain peer and management support. Activities which will accomplish this need to be planned and scheduled periodically during the activity.

- A team will naturally have diverse skills, personalities, and agendas. The diversity is beneficial if individual skills are identified at the beginning and continuing team duties are assigned based on these skills soon after the activity begins. Everyone on the team needs to be responsible for tasks that they can successfully perform.

- The structured methodology provided us with an operational framework that was valuable in keeping us focused and making efficient use of time. The specifics of this will be discussed in a paper that follows.

- The team effort really did produce better results. We had good expertise and experience on the team. Still, even the best individual contribution was weak when compared to a team collaborative effort.

- Having a support team was CRITICAL to the success. The greatest impact came from those who participated in a review capacity. Even the most brilliant idea needs a sanity check. These reviews kept us on track, added value, and accelerated our progress.

- Other support team members allowed us to keep focused on our work by making sure the facilities and supplies we needed were available.

Additional Issues Identified

The testing requirements task group was able to identify additional issues relating to the validation of CDIMs and the specification. These issues could not be resolved within the scope of the activity. They remain as issues which must be resolved within the follow-on PDES, Inc. activities and through PDES, Inc. coordination with the standards organization.

The first issue which needs resolution is the effect of CDIM validation on the topical models and other work from the standards organization. Validating a CDIM only validates the portions of models that were needed by the application. A CDIM

is validated only for the specific usages within the application context. The implication is that validation needs to occur for a variety of usages before there is a degree of confidence that the topical models in the specification are suitable for the variety of disciplines the specification is targeted to support.

The next issue relates to what information should be in the general requirements found currently in topical models. It is likely that additional information requirements will be identified for the application usages. The unanswered question is by what criteria should these requirements be evaluated to determine if any should be added to the resource pools of topical models.

The last issue is that the review of CDIM development and testing approach identified a relationship to work going on in the Application Validation Methodology Committee of the IGES/PDES Organization. Their application protocol (AP) work has similar concepts [HAR89]. The AP methodology has only recently been adopted for PDES, although the AP methodology is being tested in the IGES environment. This methodology requires further refinement in order to ensure its utility for PDES. We feel that the CDIM development and testing should precede the development of standardized application protocols.

Current Direction

There are four follow-on activities taking place. Two are developing CDIMs and two are developing testing criteria for CDIMs. This work will take three months to complete.

Terminology Defined

The following terms can be expected to be used throughout the series of papers:

> **Application Protocol** (AP) - A method to achieve consistent and reliable exchange of product definition data within a specified application area. The key components of an application protocol are a conceptual information model for the application area with supporting documentation, an application protocol format specification, and a set of application protocol test cases. [HAR89]
>
> **Assertions** - A logical expression specifying a state that must exist and/or a set of conditions that a process interface must satisfy at a particular point during process execution. [ISO89-1]

Conceptual Information Model - A description of the information requirements, relationships between informational objects, information structure, and constraints for a subject area.

Conformance Testing - The testing of a candidate product for the existence of specific characteristics required by a standard. Testing the extent to which an implementation under test is a conforming implementation. [OSI88]

Context Driven Integrated Model (CDIM) - A conceptual information model which represents the information requirements of a discipline or application usage. The model is integrated because it draws upon the resources of other models to specify shared information requirements and is not specific to an application.

Expected Result - A foreseen test outcome converted to the required form for analysis. [ISO89-1]

Fitness Test - The review and walk-through of an application reference model which demonstrates that the model is useful in a particular application area. [ISO89-1]

Integrated Model - A conceptual information model which represents the assemblage of multiple information models into a coherent, non-redundant, and internally consistent model. An integrated model is characterized by an even degree of detail and elements which are at the same level of abstraction.

Integrity Testing - Those tests applied which demonstrate that an application reference model is syntactically correct and self-consistent. [ISO89-1]

Semantics - (1) The meaning that is assigned to an item of information. [HAR89] (2) The discipline of expressing the meanings of computer language constructs in metalanguages. [ANS83]

Topical Model - A conceptual information model which represents the set of information requirements needed to represent a subject matter. A topical model is intended to be a shared resource and therefore is not expected to contain concepts specific to any particular application or industry.

Verification - The process of determining whether or not the products of a given phase of the development

cycle fulfill the requirements established during the previous phase. [IEEE84]

Viability Testing - The process of fitness testing and integrity testing. [ISO89-1]

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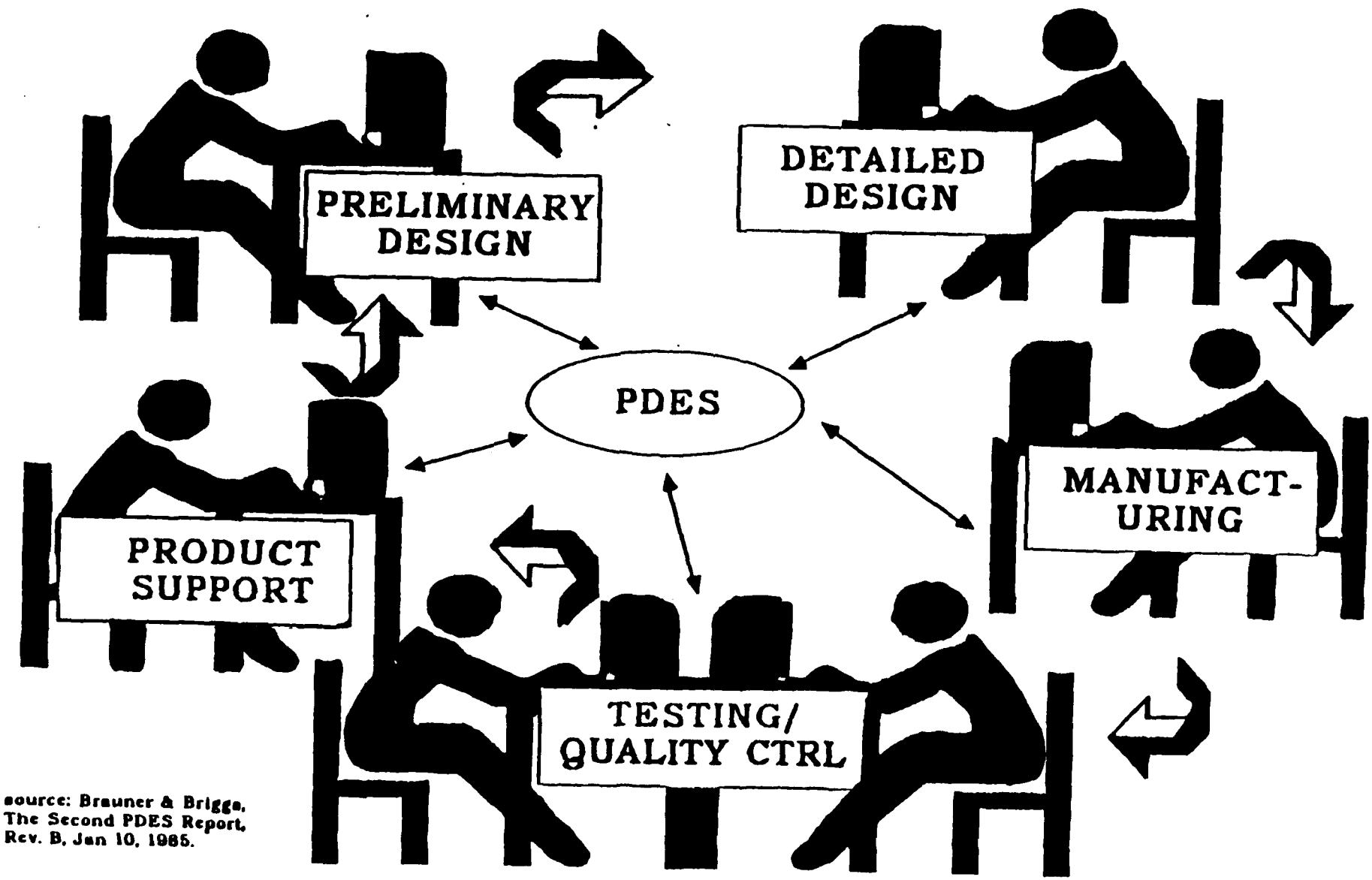

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Data modeling techniques have been used extensively in the development of an emerging standard for the exchange of product design and manufacturing information. PDES, Inc., an industry cooperative, is applying resources to accelerate the development and implementation of this emerging standard, the Product Data Exchange Specification (PDES). An objective of PDES, Inc. is to validate the completeness and usability of the specification. This paper describes some strategic and technical issues which directly impact this effort. Experience with actual validation activities identified the need to develop additional requirements documentation. This paper serves as the background for a series of papers which will describe the actual methods and processes used in the requirements specification activity. Three types of results came out of this requirements activity. The form of the project deliverables changed considerably. Insights on conducting requirements activities were identified. New issues on the relationship of this work to portions of the specification were identified.

12. KEY WORDS (Six to twelve entries; alphabetical order; capitalize only proper names; and separate key words by semicolons)

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